MODIS Semi-Annual Report
Snow and Ice Project
Reporting Period: July - December 1997
Submitted by: Dorothy K. Hall/974

INTRODUCTION

The report will consist of two sections. The first section is an update on the MODIS snow and ice products algorithm delivery. The second section, which summarizes the progress of the last 6 months, is the response to the MODIS Snow and Ice Ad-Hoc Committee's report on the progress of the MODIS snow and ice project. This was written and sent to the Ad-Hoc Committee in November of 1997.

UPDATE ON ALGORITHM DELIVERY

Version 2 of the MODIS snow data product algorithm MOD_PR10 incorporating most recent metadata requirements for the ECS version B.0 data model, including HDF-EOS structure metadata, was delivered to SDST on 28 August 1997. After interaction with SDST to resolve coding ambiguities, inconsistencies, a revised Version 2 of MOD_PR10 was delivered to SDST on 7 October 1997.

Version 2 of the MODIS sea ice data product algorithm, MOD_PR29 was delivered on 7 October 1997.

L2 granules of the snow and sea ice data products were generated using the V2 algorithms. They were then supplied to the MODLAND support team for development of the L2G gridding algorithms and generation of test L2G snow and sea ice data products.

Version 2 of the MODIS daily snow cover data product algorithm, MOD_PR10A1 was delivered to SDST on 30 December 1997.

Software tools were developed to support visualization and analysis of MODIS data products:

A procedure was developed using IDL to map the location of MODIS L2 data granules on a projection of the Earth.

A procedure was developed using IDL to map the location of MODIS L2G and L3 data product tiles on a projection of the Earth.

IDL procedures for visualizaton and analysis of the MODIS Level 2, Level 2G, and Level 3 snow and sea ice data products were developed. These procedures extract metadata and data arrays in the products, and display listings of the metadata and display the data arrays using standard color coding to make color images of the data for user interpretation.

Procedures for visualization and analysis of MODIS data input products were also developed.

The Level 3 Snow algorithm was successfully run to completion on 17 December 1997. Working from code written earlier in the year by Hugh Powell, metadata handling routines were added by Jon Barton, and some of the existing routines, both data handling and metadata handling, were modified to provide more robust logic.

Text of Ad-Hoc Report

Text from the MODIS Ad-Hoc Snow and Ice Products Committee recommendations is in bold. Responses to those recommendations are in plain text.

Our present concerns include:

1. The SNOMAP and ICEMAP algorithms should be independent of atmospherically corrected surface reflectances, which may unnecessarily complicate the cryospheric retrievals.

In discussions with Dr. Eric Vermote, who is developing the atmospherically-corrected surface reflectance product for MODIS, we have found that his algorithm is not suitable for use at this time over snow and ice because of its inability to characterize the atmospheric aerosols over snow and ice, and the product is not generated poleward of 70°. Therefore we will not be using this product as input to our snow- and ice-mapping algorithms in the at-launch time frame.

2. These products will only be available ca. 3 days after data collection. Operational users require such products within 24 hours of overpass.

Considerable efforts have been underway in order to ensure that the MODIS snow maps be available within 24 hours of acquisition. By having the MODIS data products archived at NSIDC at Level 2 (L2) rather than L2G (L2 gridded), it should theoretically be possible for a user to obtain the maps within about 6 hours after acquisition, from NSIDC. These maps would be based on a swath of MODIS orbit, not the daily composited data. The daily composite maps should be available approximately 30 hours after acquisition. This is because all the orbits in one day must be acquired and then composited before the daily product can be produced.

The proposed plan for MODIS snow and ice products is the following:
1) GSFC will generate the L2 snow and ice products and ship them to NSIDC with the L1b geolocation files. These will be used to generate the L3 gridded products at NSIDC.
2) GSFC will also generate the L2G-sinusoidal grid snow and ice products and ship them to NSIDC. NSIDC will generate the L3 sinusoidal grid from this product.

3) NSIDC will archive and distribute the L2 products, and the L3 polar and sinusoidal products.

3. The proposed sinusoidal projection is not sufficient for the cryospheric community.

By having the L2 MODIS maps, it should be possible for NSIDC to put the data into other projections, including the EASE-Grid. L2G data, with pointers to the sinusoidal grid, will be produced at Goddard, and distributed at NSIDC as L3 products. The L2 data, to be sent to NSIDC, can be put in the EASE-Grid by NSIDC if they are provided with funding adequate to support that task. There are several advantages to archiving L2 data at NSIDC. First, the L2 data set is smaller to archive than L2G data. Secondly, L2 data can be used to produce snow maps in near-real time. Thirdly, L2 data can be used to produce gridded maps in projections other than those supported by ECS.

4. Sea ice algorithm testing is not being conducted for the melt season.

No plans for field campaigns or other activities to support testing or validation of the sea ice algorithm during the melt season have been made by us. Reliance will be placed on independent validation studies. Drs. Shusun Li and Martin Jeffries of the University of Alaska were recently selected to lead an EOS/MODIS project that will validate the MODIS sea ice products in the Antarctic. Their research will involve the characterization of the accuracy of the MODIS snow and ice products in the Antarctic, and identification of sources of errors. Research will be conducted from the R. V. Nathanial B. Palmer ship in the Ross Sea in 1998 and 1999. We will work with Drs. Li and Jeffries as necessary to help their validation efforts.

Recommendations:

The Adhoc Advisory Committee wishes to make the following recommendations which we feel warrant attention by the MODIS team. The recommendations deal primarily with the pre-launch interval, at least work on them should continue or commence during this period. However, efforts on most will likely follow on into the post-launch domain.

1. Tune the SNOMAP algorithm for land cover differences amongst major biomes.

Considerable work has been undertaken in order to study the differences in the accuracy of the MODIS snow-mapping algorithm (formerly called SNOMAP) to map snow in different biomes. Measurements of the accuracy of the algorithm in the following land covers have been assessed: agriculture, prairie, alpine, coniferous forest, deciduous forest and tundra. Field measurements have been made in all of these areas, simultaneous with aircraft and/or satellite overpasses during conditions of continuous snow cover. Percent snow cover mapped has been measured. Results show that the algorithm can map almost

100% of the snow cover in agricultural, prairie and tundra areas that we studied, about 95% in the alpine area studied, and from about 80-90% of snow in forested areas. In short, the errors in mapping snow using the algorithm on a global basis are primarily due to the global forest cover. Both the type and density of trees affect the accuracy of snow mapping.

We have been working on the determination of global errors that are expected using the future MODIS snow maps (also see p. 9 under "Global Errors in Snow-Cover Mapping"). Using the EROS Data Center (EDC) global land cover maps, we have mapped the percentage of eight different land covers above the average monthly snowline as determined from the NOAA/NESDIS maps in North America and Eurasia. Preliminary results show that the accuracy of snow mapping generally decreases as the snowline moves southward because there are more trees in more southerly latitudes above snowline. Work is in progress to estimate the accuracies, but preliminary estimates indicate that the accuracy of the global snow cover maps could range from 5-12%, depending on the month. Accuracies in the various cover types have been determined from field measurements conducted in southern Saskatchewan in 1995, central and northern Alaska in 1995 and New England in 1997. These accuracies, determined from the above field measurements, may not be representative of similar cover types globally, but this is the information we have at this time. More field measurements are planned beginning in the 1998-1999 winter.

2. Evaluate the feasibility of assessing forest cover density using scatterometer data (e.g. approach of Chris Neale at Utah State University)

Christopher M.U.Neale at USU research interests are with SSM/I for land surface and snow detection. There is a recent paper by Neale in IEEE Transactions on Geoscience and Remote Sensing (35(4) 801-809).

A researcher focusing on scatterometer data is David Long at Brigham Young Univeristy, a member of the NASA Scatterometer (NSCAT) team with extensive experince in radar remote sensing. He is the one who developed a technique of extracting 8-km resolution data from the 50 km resolution NSCAT data refered to as the SIRF resolution enhancement algorithm. SIRF images have demonstrated the ability to enable the discrimination of tropical vegetation types and have been very useful in polar ice studies. It appears that extraction of forest cover density from scatterometer data may be possible someday. Current work demonstrates that the NSCAT could be used to map forest-cover types, notably in the Amazon Basin. A measure of forest density is not currently a routine data product, nor has a mapping of density been done per se. It is implied that forest density is a factor in the ability to map forest cover with scatterometer data but, density is not presented as an independent component.

Forest density detemined by a scatterometer may be affected by snow cover. The scatterometer signature is affected by snowpack density and soil moisture, thus the signature from a snow-covered forest may be a mix of forest and snow. Change detection techniques may be useful for sorting out the effects of snow.

ADEOS failed on or about 2 July 1997 so no more NSCAT data being collected. Another NSCAT is planned for launch in 1999, and one may be launched sooner in reaction to the loss of ADEOS. There are other scatterometers on ERS-1 and on a NOAA platform.

The Seasat scatterometer (SASS) and ERS-1 scatterometer (Escat) data have been processed with the SIRF resolution enhancement algorithm. This algorithm was developed by the MERS group at BYU to genetate enhanced resolution scatterometer imagery.

Other work has been done in an attempt to determine the errors of mapping snow cover in various vegetation-cover densities under conditions of continuous snow cover in central Alaska in conjunction with the April 1995 field and aircraft mission. After determining integrated reflectance, a forest-density map of parts of central Alaska was constructed. We then divided the MODIS Airborne Simulator (MAS) scene into 2 general categories: > 50% and < 50% vegetation-cover density. In the part of the scene that was mapped as having a vegetation-cover density of <50%, the snow-mapping algorithm mapped 96.41% snow cover. In the part of the scene that was estimated to have a vegetation-cover density of >50, the snow-mapping algorithm mapped 71.23% snow cover. Overall, the accuracy of the snow-mapping algorithm is about 87% for a 13 April 1995 MAS scene with a variety of surface covers (Hall et al., in press) (*Appendix 1*).

3. Continue evaluating the utility of employing MODIS band 7 (2.1 μm) to better assess snow cover under vegetation canopies.

The possibility of using MODIS band 7 instead of MODIS band 6 in calculation of the NDSI has been investigated. MODIS band 6 was originally selected because of the history of using wavelengths in that region for cloud detection. Investigations using a simple forest canopy model (GeoSAIL) show that NDSI values calculated using band 7 for snow-covered coniferous forests are much closer to snow-free conditions than if band 6 is used. This suggests that band 6 is better for use in coniferous canopies. Secondly, use of band 7 would require recalculation of the original NDSI threshold. While using MODIS band 7 to calculate the NDSI still may have some promise for improving classification accuracy for some deciduous canopies, application in a global algorithm is not warranted until comparisons can be made with the MAS data in areas where adequate canopy information is available.

Instead, improved classification accuracy in forests has been approached in a different manner (Klein et al. 1997; Klein et al. in review). Using Landsat TM images covering the BOREAS southern study area, located at the southern border of the boreal forest near Prince Albert National Park in Saskatchewan, it was found that snow-covered and snow-free forests can be clearly distinguished using NDSI in combination with NDVI. This approach is now being tested using MAS and TM in other areas. Preliminary results for the New Hampshire and New York WINter Cloud Experiment (WINCE) sites show that considerably more snow (up to 3X) is mapped using the new technique. (*Appendix 2 and 3*)

4. The following ice products should be generated: a) ice extent derived from reflectance data, b) ice surface temperature, and c) a combined extent product using reflectances and surface temperature.

The MODIS sea ice product now includes six data arrays:
1. Sea ice extent as determined from reflectance data (using MODIS bands 2,4,6).
2. Sea ice extent per pixel quality assessment array. The per-pixel quality assessment array is an imposed requirement from the EOSDIS project. For an explanation of the quality assessment array, refer to the product specifications or user's guide (in preparation).
3. Ice Surface Temperature (IST) as determined by a split-window technique.
4. Ice Surface Temperature per pixel quality assessment array.
5. Sea ice extent as detemined by temperature.
6. Maximum sea ice extent by melding of the sea ice extents by reflectance and temperature.

Classification of ice type by combination of temperature and reflectance is being investigated. These sea ice components have been prototyped with MAS data. We are currently writing and coding the MODIS sea ice algorithm, Version 2, to generate these data arrays. [A paper on MODIS sea ice algorithms has been prepared and is currently being reviewed by the authors.] (*Appendix 4*).

5. Explore implementing the AVHRR sea ice motion technique using MODIS sea ice retrievals.

We do not have the budget at this time to do any ice-motion studies.

6. In the pre-launch interval, utilize TM, AVHRR and ERS data in combination with field programs such as SIMMS (Seasonal Sea Ice Monitoring and Modeling Site) for ice algorithm testing. If launch occurs on schedule, utilize Surface Heat Budget of the Arctic Ocean (SHEBA) experiment data.

It is our hope that validation activities such as this one will be performed by other investigators. We do not have the budget to do any sea ice-validation work.

7. Assess the sign and magnitude of SNOMAP and ICEMAP biases seasonally.

This is an activity that will need to be undertaken following launch when we will be able to compare MODIS snow and ice maps with maps derived from other sources, e.g.

NOAA/NESDIS and NOAA/NOHRSC. Determining seasonal biases will require several years of MODIS and ancillary data.

8. Quantify differences between algorithm products generated with and without atmospheric surface reflectance corrections

The effects of using the atmospherically-corrected surface reflectance values (MOD09 products) rather than L1-B at-satellite radiances are being investigated for three TM scenes covering Glacier National Park, Montana. These scenes cover a wide range of snow cover, illumination, and cloud conditions. In the process of this study, we uncovered a problem with the atmospheric-correction routine. Pixels containing a high percentage of snow were being incorrectly flagged as clouds. Consequently, no reflectance values were being produced for the majority of 'pure' snow pixels. As soon as the atmospheric correction is rerun on the scenes, the effect using atmospherically-corrected images can be properly ascertained for both the original and revised snow-mapping algorithms. We are working with another investigator, Dr. Eric Vermote, on a second TM scene on which we will do a comparison of results of snow mapping before and after atmospheric correction. In addition, after launch, comparison studies will be done after the atmospheric-correction product has been checked out and validated.

9. Continue working with the MODIS cloud mask team to define when and where to map snow and ice parameters.

Collaboration with the MODIS cloud mask team is ongoing. The cloud-mask algorithm has been used with MAS snow and sea ice data. A jointly-authored paper has been drafted describing results of using the cloud mask with the sea ice algorithm with MAS data (*Appendix 4*). Collaboration has resulted in the use of a modified NDSI with snow/ice criteria test integrated into the cloud-mask algorithm. Also a greater understanding of how to use the cloud flags and which cloud tests provide reliable results over snow or ice continues to be achieved through the collaboration.

10. Address issues of mapping snow and ice under cloud shadows.

It appears that snow and ice can be mapped in many cloud shadows, based on TM and MAS scenes that have been studied to date. Mapping snow under cloud shadows is more of an issue with the daily product than with the composite products. There will be fewer clouds in the composite products.

11. Develop in conjunction with the DAACs a plan for post-launch quality control of daily and composite products. This should include operator review and comparison of MODIS products with products from alternative data sources.

Discussions are in progress with NSIDC and the issue is included in quality assessment plans. There is also a component of quality assessment that can be done at the MODLAND operational quality-assessment facility. We will perform a considerable amount of hands-on quality control of snow and ice products, particularly in the first year after launch. We will do this with the L2 and L2G data at Goddard and the L3 data at NSIDC.

12. Snow and ice products should be made available within 24 hours of satellite overpass to be of maximum value to the operational community.

This is addressed in the beginning under present concerns #2 (see p.1).

13. Level 3 products should be generated and archived in EASE-grid (Equal Area SSM/I Earth-grid).

This is addressed in the beginning under present concerns #3 (see p.2).

14. The option for user specified temporal composite intervals should be implemented at NSIDC.

We agree that this is a desirable goal. Our compositing scheme calls for daily composites (composites of the orbits in each day), 8-day and monthly composites for the 500-m snow product, the 1-km sea ice product and the climate modeling grid (CMG) snow and ice products. This can potentially be implemented at NSIDC if NSIDC has the resources to perform this task. Otherwise, investigators can make their own composite maps from the daily maps. We may be able to provide unsupported IDL code to do the temporal compositing.

15. Continue exploring strategies for post-launch enhancements in the products.

MODIS band 7 may also be employed in post-launch versions of the snow-mapping algorithm. We are currently adapting the approach used to detect aerosols in MODIS imagery (Kaufman and Tanré, 1996) to detect snow in pixels where it occurs as a minor constituent within otherwise forested pixels.

The approach assumes that in forested areas reflectances are somewhat correlated between the MODIS visible to short-wave infrared bands. Assuming a correlation between the MODIS 0.66 and 2.2 micrometer bands, it is possible to estimate the forest contribution to the 0.66 micrometer reflectance based on the pixel's reflectance at 2.2 micrometers ($r_{2.2}$) where the reflectances of both snow and aerosols are quite low. If a snow reflectance value (r_{snow}) is also assumed, then an index value related to the fraction of the pixel covered by snow can be calculated as:

$(r_{snow} - 2r_{2.2})/r_{snow}$.

The effectiveness of this approach at detecting snow cover under dense coniferous canopies was tested using atmospherically-corrected Landsat Thematic Mapper scenes acquired over Glacier National Park. In areas where the current MODIS snow cover algorithm was not able to correctly identify the presence of snow, observable differences in the snow fraction index value were found to occur. This approach could improve the accuracy of snow maps produced from MODIS data in heavily forested areas and may provide a computationally-frugal means of deriving sub-pixel estimates of snow covered area for certain forested areas. An abstract on this subject has been submitted for presentation at the AGU meeting in December 1997 in San Francisco (*Appendix 5*).

NEAR-TERM PLANS

Preparation of User's Guide

A MODIS Snow Products User's Guide is being drafted. The purpose of the user's guide is to described the sequence of snow products, from the L2 swath to L3 gridded and composited data and to describe and explain the data and metadata in the HDF-EOS data product files. Many users are unfamiliar with the HDF-EOS data-product format so a brief overview of HDF-EOS is given to orient the user. The logic of data product generation is briefly described. The data content of the products is described in detail. Detailed description of summary statistics and information generated during execution of the algorithm and stored as local attributes (local metadata) with the scientific data sets is given. Graphical examples of data products are included. The snow product user's guide has undergone several revisions to date with more expected. A Web-based version of the user's guide will be created.

A MODIS Sea Ice Product User's Guide is expected to be drafted after putting the snow product user's guide into final form so that it can be used as a template for the sea ice product guide.

Algorithm Deliveries

The code for the processes that generate the products is delivered to the Science Data Support Team (SDST) which checks for conformance to coding standards, then implements them in the Team Leader Computing Facility (TLCF), then deliveries a Production Generation Executive (PGE) for the products to the ECS DAAC for integration in the Science Data Processing Segment (SDPS). Version 2 code for the Level 2 snow and sea ice products was delivered to the SDST in early October 1997. That code and products were created from MODIS synthetic data sets. Revision of Version 1 code for the Level 3 products and creation of code for the CMG products is underway with the goal of completing and delivering Version 2 of all the products, except monthly ones, by launch of the EOS-AM1 platform in June of 1998.

Vegetation Type and Density Map of Central Alaska

Work has been undertaken to estimate the vegetation density in central Alaska in order to determine errors in snow mapping in various vegetation-cover types (see p. 2 under Recommendations #1). Results were reported in Hall et al. (in press) (*Appendix 1*). In order to estimate the vegetation density, we employed a technique using reflectance values devised by Robinson et al. (1985) and used by Foster et al. (1994). We also asked Dr. Dave Verbyla, University of Alaska, under contract, to generate a vegetation-cover density map from a TM scene in central Alaska. We have just received this and in the near future will be comparing the Verbyla map with the map we generated for the Hall et al. (in press) paper. Depending on the results, we may gain confidence in our ability to estimate vegetation-cover density using reflectances. This helps in the snow-map validation efforts.

Global Errors in Snow-Cover Mapping

With the advent of Moderate Resolution Imaging Spectroradiometer (MODIS) data, to be available following the June 1998 launch of the Earth Observing System (EOS) satellite, global snow-cover mapping will be performed automatically, and on a daily basis at a spatial resolution of 500 m. The accuracy of the derived snow-cover maps will be determined based on comparisons with results from other snow maps as well as from ground measurements. Previous work has shown that the accuracy of snow mapping is dependent upon land cover. In particular, the greatest uncertainty in snow-mapping accuracy is found within the world's forest cover. In the forests, the accuracy of snow mapping can vary widely, at least in part due to the type and density of the trees. Using the EROS Data Center (EDC) land-cover maps of North America and Eurasia, we have classified the Earth's land cover into 8 different categories: mixed agriculture and forest, forest, barren/sparsely vegetated, tundra, grassland/shrublands, wetlands, snow/ice and water. We have also mapped the average monthly snowline position, as determined from the NOAA National Environmental Satellite, Data and Information Service (NESDIS) maps onto maps of North America and Eurasia. For the 10 months (July and August are excluded), the land cover in each of the 8 categories is shown for the areas north of the snowline. Based on previous field, aircraft and satellite results, snow-mapping errors are assumed for each of the 8 categories. Results show that the greatest errors in snow mapping can be expected in North America in November through April, and in Eurasia in April. If we use an error of 20% for snow mapping in the forested areas, then the potential maximum estimated snow-mapping error for North America is 11.3%, and 12.9% for Eurasia; the minimum estimated global error is 5%. By this reasoning, the global error in snow mapping would be approximately 12%. These numbers will be continually refined as we acquire several years of MODIS global snow-cover data beginning in 1998.

Climate Modeling Grid (CMG)

A climate modeling grid (CMG) snow-cover product is being developed by Jon Barton/GSC/Code 974. The daily CMG for snow cover will be in the integerized sinusoidal projection at 1/4 X 1/4° resolution. The CMG will be in EOS hierarchical data format (EOS-HDF) and will contain two scientific data sets (SDS). The first SDS is a three-dimensional byte array, where the dimensions are 1440 X 720 X 3. Each cell in the grid has three days of data.

In the assembling of the global product from the 500 X 500-m resolution daily snow tiles, each 1/4 X 1/4° pixel represents the average value of about (depending on latitude) 2500 of the 500 X 500-m pixels. The first data layer represents the percentage of good, clear pixels (i.e. not cloud obscured and on which a decision has been made) in which snow occurs. The second layer contains the percentage of those 2500 pixels that were cloud obscured. The third data layer in the array represents the percentage of these 2500 pixels that contain data on which no decision was made, for whatever reason, regarding the existence of snow.

The second SDS in the data file contains the quality assurance (QA) information for cells in the CMG. This is a one byte, two-dimensional array. Each pixel contains a value between 0 and 3. This data has been taken from the 2500 500 X 500-m pixels of the daily snow-cover product that were combined in making the CMG, and unless 100% of these pixels are abnormal, cloud obscured or invalid, the QA for the CMG will show a nominal result.

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